

CRAMP THRESHOLD FREQUENCY IN A FATIGUED FLEXOR HALLICUS
LONGUS COMPARED TO A RESTED FLEXOR HALLICUS LONGUS

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Title

Cramp Threshold Frequency in a Fatigued Flexor Hallicus Longus
Compared to a Rested Flexor Hallicus Longus

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The Supervisory Committee certifies that this *disquisition* complies
with North Dakota State University's regulations and meets the accepted
standards for the degree of

MASTER OF SCIENCE

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ABSTRACT

Muscle fatigue is thought to cause a person's exercise associated muscle cramps (EAMCs). However, there is little support that fatigue is the reason EAMCs occur. We examined if a fatigued muscle would make it more susceptible to an EAMC. Subjects were exposed to a cramping protocol, which included two seconds of stimulation with a minute rest until a muscle cramp was induced. The participant rested for 30 minutes and then completed a fatigue protocol. The subject performed reps of toe curls against a resistance band (sets of 10 curls with a one minute break in between sets) until muscle failure. Following fatigue, participants immediately completed the cramping protocol. Paired t-test analysis revealed that the change in cramp threshold frequency was not statistically significantly different in a fatigued flexor hallicus longus than in a rested flexor hallicus longus ($t(9) = 1.69, p > .05$). Although not statistically significant, results indicated a difference between the mean cramp threshold frequency in a fatigued flexor hallicus longus ($25.80\text{Hz} \pm 7.33$) when compared to a rested flexor hallicus longus ($28.20\text{Hz} \pm 7.91$) condition. Fatigue does not play a factor on EAMCs. Future studies should focus on a larger sample size and evaluation of other possible factors that influence EAMCs.

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CHAPTER 1. INTRODUCTION

Muscle cramps are a painful, spasmodic contraction of skeletal muscle that occurs during or after physical exercise¹ and are a common injury affecting many physically active individuals.²⁻⁴ Research has shown that exercise associated muscle cramps (EAMC) are commonly seen in many different sports and activities. Cooper et al.² found that 73.4 % of football players experienced heat cramps. One of the first studies done in 1956 discovered that 95% of physical education students had experienced spontaneous cramps in their lifetimes with 26% experiencing cramps after exercise. Muscle cramps have also been seen in triathletes: 62-78% have complained of exercise associated muscle cramps while racing and training.⁴

Researchers have hypothesized that neural control is responsible for EAMC.^{5,6} The neuromuscular theory of EAMC proposes that fatigue creates an imbalance between excitatory and inhibitory signals, which alter excitability alpha motor neuron. Support for this theory comes from observations that fatigue changes muscle spindle and Golgi tendon organ (GTO) activity.⁶ Therefore, EAMC often occurs at the end of races.⁷ By stretching EAMCs are alleviated when the muscle is contracting in an already-shortened position which may be because GTO decrease their firing rate in shortened positions.⁶ Other popular theories of EAMCs causes include environmental factors, dehydration, and electrolyte imbalance.^{4,8,9}

EAMCs are difficult to study in humans because EAMCs are unpredictable. To solve this problem, researchers have developed ways to electrically induce cramps in a laboratory setting.^{10,11} Cramp threshold frequency (TF) is the minimum electrical stimulation frequency at which a muscle can cramp⁵ and is thought to be an indicator of a

person's cramp predisposition. Low thresholds indicate greater risk of EAMC, while high thresholds indicate a lower risk.

Overloading the alpha motor neuron will disrupt the normal signals telling the muscle to relax forcing the muscle to stay in its shortened position.⁶ Staying in a shortened position will then cause the muscle to tire and fatigue. Electrical stimulation is applied to the fatigued muscle determines if the muscle has decreased its threshold frequency.¹⁰ The TF change determines if the person became more susceptible to EAMCs.

Purpose of Study

The purpose of the study is to determine if fatigue contributes to EAMCs in individuals who have a history of EAMC. Cramp threshold frequency will be measured using the flexor hallicus longus.

Research Question

1. Is cramp threshold frequency lower in a fatigued flexor hallicus longus than in a rested flexor hallicus longus?

Study Significance

The significance of this study is to alert medical professionals to the dangers of EAMCs. EAMCs caused from fatigue show that a person's body is beginning to break down and must be taken care of immediately. Also, the study can assist athletic trainers and medical to the best care choices for a person experiencing EAMCs.

Definition of Terms

Electrolyte: Substance that dissociates into ions when fused or in solution, thus becoming capable of conducting electricity.¹²

Exercise Associated Muscle Cramp (EAMC): Painful, spasmodic contraction of the skeletal muscle that happens during or right after exercise.¹

Fatigue: Incapacity to reach or maintain an expected or required effort level, as well as to the inability to continue the exercise at a specific work intensity.¹³

Golgi Tendon Organ (GTO): Any of the mechanoreceptors arranged in series with muscle in the tendons of mammalian muscles, being the receptors for stimuli responsible for the lengthening reaction.⁷

Muscle Cramp: A painful spasmodic muscular contraction.¹

Muscle Spindle: A fusiform end organ arranged in parallel between the fibers of skeletal muscle and acting as a mechanoreceptor, being the receptor of impulses responsible for the stretch reflex.¹³

Plasma Volume: The total volume of blood plasma, i.e., the extracellular fluid volume of the vascular space.¹⁴

Threshold Frequency (TF): Minimum electrical stimulation frequency at which the muscle cramps.¹²

CHAPTER 2. LITERATURE REVIEW

The purpose of this literature review is to determine if fatigue contributes to EAMCs in individuals who have history of EAMC. Cramp TF was measured using the flexor hallicus longus. This study will investigate if cramp threshold frequency is lower in a fatigued flexor hallicus longus than in a rested flexor hallicus longus.

Defining Muscle Cramps and Fatigue

Muscle cramps are a painful, spasmodic contraction of skeletal muscle that occurs during or after exercise.⁸ Bergeron states that skeletal muscle cramps are common in sports and numerous other physical activities.⁸ This definition will be used to explain muscle cramps throughout this literature review.

Fatigue has many different definitions depending on the situation. In this literature review muscle fatigue will be referred to as fatigue. The concept of muscle fatigue is usually associated with the incapacity to reach or maintain an expected or required effort level, as well as to the inability to continue the exercise at a specific work intensity.¹² Another useful definition of muscle fatigue, is defined as a transit loss in the ability to generate force.¹³ The first definition of fatigue will be the definition used throughout the following literature.

Prevalence of Muscle Cramps

Muscle cramps are a common injury in athletes who participate in a variety of different activities at all levels, from elite to recreational. Thirty to fifty-three percent of American football players have experienced cramps.⁸ In a study done by Schweltnus, he looked at 1383 marathon runners with a history of cramping and found the following results: 1.) all the runners (100%) reported cramping in the latter half of the race, with

most (67%) reporting cramping immediately after the race. 2.) most cramps (62%) reportedly lasted longer than 30 seconds and 3.) most runners (71%) reported three or more cramping episodes. 4.) most cramps (57%) were moderate to severe in intensity.¹⁴ These findings show that cramping can be extremely common in long distance runners.¹⁴ Fitness level may not increase nor lessen the chance a person will become subject to EAMC. Schweltnus and Collins⁴ recruited 210 Ironman triathletes, 43 of the participants experienced EAMCs. Even the most highly trained athletes can develop cramps that come without any warning and are debilitating to their actions.⁴

Environmental Theory

One of the popular theories for cause of cramping is that the environment is a key component in EAMCs. Heat and humidity are thought to be a culprit for those who often experience cramps when they exercise and perform physical activity. Stone et al¹⁵ had 997 athletic trainers answer a seven-question survey on what they considered to be an important factor influencing muscle cramps in their athletes. The top two answers were humidity (83.6%) and temperature (76.7%). Recently, researchers observed that the majority of cramping (95%, 87 of 92) occurred in hot months, specifically, when football players exercised in environmental conditions in which the risk of developing heat illness was “high” or “extreme”.^{2,27} Schweltnus states that more than a hundred years ago it was commonly thought that heat is where a majority of cramping occurred; however, the cramps were accompanied by profuse sweating.¹⁴ Therefore, individuals should be careful when they are being active in high heat and humidity.

It was also observed that EAMCs have been seen in runners exercising in moderate to cool temperatures¹⁴⁻¹⁶ and in swimmers when exposed to extreme cold.¹⁴⁻¹⁶

Also, Schwellnus suggested passive heating alone (at rest) does not result in muscle cramps, and cooling does not relieve muscle cramps; therefore, it would appear that heat alone is not a direct cause of muscle cramping during exercise. The term “heat cramps” is misleading and use should be discouraged.¹⁴ Individuals with a history of EAMC should practice preventative actions even in cool weather because a cramp can still occur.

The environmental theory can be a challenging one to examine and test in a controlled setting. Testing in a field setting can make it hard to get the desired number of subjects with muscle cramps.¹⁵ The results may not be reliable because there is no true measure of the level of cramp or what has caused the cramp.²

When cramping is done in the laboratory setting results may not hold true to what happens in a natural environment. To expose a person to elements that trigger a muscle cramp, he or she are usually placed into a heat chamber. Laboratory settings can be desired though for the ease of taking measurements and getting samples from a person.

Dehydration Theory

The dehydration theory may be the most popular theory suggesting why cramps occur during or after exercise.¹⁷ Schwellnus and Collins stated that the body does not store enough water for exercise and athletes do not ingest enough water to replace the amounts lost during exercise.⁴ It is hypothesized that EMACs are caused as the result of fluid and electrolyte depletion, which results in the sensitization of select nerve terminals.¹⁸ Other researchers propose that dehydration has caused a contracture of the interstitial space, which increased the mechanical pressure on nerve terminals, thus causing a cramp.⁸⁻¹⁸ Stone’s survey of athletic trainers found that athletic trainers believe

that dehydration was the most common cause 71.7% of EAMCs.¹⁵ It is common practice in the field of athletic training to explain that dehydration caused an athlete's EAMC.

Plasma volume losses in 24 runners with EAMC (5.2%) were not significantly different from those of runners with EAMC (4.4%), nor were losses in blood volume (1.7% and 1.3%) or body weight different.¹⁹⁻²⁰ These findings suggest that dehydration is an unlikely sole contributor for EAMC. Literature has not found a correlation between body weight loss from fluid depletion and EAMC.^{4, 11, 21, 22} Lastly, if EAMC were caused from dehydration, the simple cure would be fluid replacement.²³ However, when carbohydrate-electrolyte fluids were ingested at the same rate that matched the sweat loss, EAMC still occurred in (9 of 13) 69% of athletes, whereas (7 of 13) 54% cramped when not given any fluid.¹

The dehydration theory has limitations. Cause and effect cannot be made from observational data when tested in the fields; cause and effect can only come from meta analysis which can only be done in a controlled setting.²⁴ Another limitation on this theory is that EAMC may appear in the presence of significant electrolyte and or fluid losses during exercises.²³ To find whether or not dehydration is the reason behind causing muscle cramps an individual must be put in environment that controls all other possible variables such as heat and humidity. This is very challenging to attempt because the individual must be dehydrated via exercise and then a cramp induced.

Electrolyte Imbalance Theory

Electrolyte imbalance is another popular theory used to explain why muscles cramp. Eichner postulates that sweat glands are unable to reabsorb sodium at "high" sweat rates.²⁵ High sweat loss could be thought of as a warning sign to those cramping

because of dehydration-electrolyte imbalance.³ An athlete who has been sweating extensively lost appreciable sweat electrolyte particularly sodium and chloride.⁸ More support for this theory comes from researchers noticing large amounts of sweat being lost by exercising athletes.^{8, 26} High volumes of fluid loss are more common in hot and humid conditions as compared to other temperature situations. The fluid loss required to prompt muscle cramping is not well described; however, an estimated sweat-induced loss of 20%-30% of the exchangeable sodium pool has been noted with severe muscle cramping.^{8, 26} The resultant loss of plasma volume causes a mechanical deformation of nerve endings and increases the surrounding ionic and neurotransmitter concentrations, which then causes selected motor nerve terminals to become hyper-excitabile and spontaneously discharge.^{14, 26, 27} How readily electrolyte depletion occurs depends on how much fluid is lost. With the consistent sweat loss the serum sodium concentration is typically maintained or elevated, along with potential changes in sweat gland function or sympathetic nervous activity that would increase sweat sodium concentration.²⁸ This would explain why muscle cramps are so commonly seen within athletes who participate in long strenuous sports and activities.

The electrolyte imbalance theory has been investigated. Specifically, Schwellnus¹¹ examined the electrolyte theory with 1383 marathon runners and triathletes. Serum levels were compared in a cramp group and a non-cramp group; there was no significant difference between the groups. A dissociation between EAMC and serum sodium concentrations were noted.¹¹ Also, as cramps subsided and became asymptomatic, there were no changes in serum levels.¹¹ This finding of a dissociation between EAMC and serum concentrations has more recently prompted the proponents of the electrolyte

imbalance theory to hypothesize that the mechanism for EAMC is increased sweat sodium concentrations or “salty sweating”.^{25,26,27} Therefore, it is concluded that sodium depletion may cause EAMC.^{25, 26,27} These findings suggest sodium is likely a variable behind a person’s exercise associated muscle cramp.

The electrolyte imbalance theory cannot stand-alone. Sweat sodium concentration is always a hypertonic solution.¹³ Significant loss of sodium through sweat can therefore only occur if there is also a large loss of fluid.^{14, 16} There has not been plausible evidence demonstrated to show that the mechanism of salty sweat is the only source needed to cause muscle cramping.²⁵ It is thought that dehydration and muscle fatigue can be considered additional predisposing factors along with sodium depletion to cause EAMC.^{22, 25} It is challenging to isolate the electrolyte loss without an additional factors being affected.

The electrolyte imbalance theory cannot fully explain muscle cramps that do not occur in hot and humid conditions. Maughan²⁹ reported that 18% of 15 marathoners still developed EAMC even though the ambient temperature was 10 to 12 degrees Celsius. Recent studies have consistently shown that athletes suffering from acute EAMC are not dehydrated, nor do they have disturbances in serum osmolality or serum electrolyte concentrations.^{21, 22} Other studies have shown that both electrolyte depletion and dehydration are systemic abnormalities.^{21, 22} The symptoms are classically local and are confined to the working muscle groups.^{21, 22} There are multiple studies showing the electrolyte imbalance theory has little evidence to support electrolyte imbalance.

Neuromuscular Theory

The neuromuscular theory also known as the fatigue theory of EAMC proposes that muscle overload and neuromuscular fatigue cause an imbalance between the excitatory impulses from golgi tendon organ (GTO). A study described the neural theory as the muscle fatigue hypothesis.²⁶ These EAMCs tend to occur when the muscle is contracting in an already-shortened position.²¹ The reduced tension is thought to likely lower the inhibitory feedback coming from the GTO afferents, predisposing the muscle to cramp due to the imbalance between the inhibitory and excitatory alpha motor neuron.³⁸ The neural theory suggests that exercise can prompt an excitatory alteration (increase) in muscle spindle activity and a decrease in GTO inhibition; leading to abnormal motor neuron control and sustained motor neuron activity.²⁶ Muscle spindle activity is decreased in a fatiguing muscle and is also associated with the decreased GTO discharge.³¹ In other words, shortened muscles with sustained contractions may be particularly vulnerable to such cramping,³⁰ and the GTO inhibitory activity is normally decreased in a shortened position therefore cannot respond to the muscle tension.³¹ Collectively, the changes in the muscle receptor activity can potentially result in the imbalance between facilitator and inhibitory feedback.¹⁵ The imbalance results in excitation of the alpha-motor neurons, which leads to the cramp.¹⁵ Because of the neural changes happening it can be concluded that cramps come from the spinal cord and not because of different pressures in the muscles.

Studies that have examined the plausibility of the neuromuscular system's role in EAMC are much stronger than those studies for dehydration of animals,^{21,31} exercising humans,^{3,21} and stretching for EAMCs.^{21, 32} It is easier to show that neuromuscular

intervention causes EAMC and is more probable than that of dehydration.^{10,23} When measuring cramp threshold frequency (TF) the minimum electrical stimulation frequency needed to cause a muscle cramp,⁹ determines the predisposition of the muscle cramping.⁴ Individuals who have experienced muscle cramps before generally have a lower threshold frequency than those who have never experienced a cramp.²³

To relieve EAMC, stretching is the common practice and yields the most positive results.²³ When looking at stretching from the neuromuscular aspect, it is thought to relieve EAMC by using the autogenic inhibition.²³ Stretching increases the tension in the muscle's tendon, resulting in GTO activation and an increase in inhibition of the alpha motor neuron, which may restore the physiological relationship between excitatory and inhibitory impulses to the alpha motor neuron.²¹ Stretching allows the stressed alpha motor neuron to relax and tells the GTO to take over and allow the person to have relief from the muscle cramp that he or she are experiencing.

Like other theories there are limitations to the neuromuscular theory. The results of altered muscle spindle and GTO activity rely on difficult methods with inconsistent results.²³ The majority of Golgi tendon organs afferents only have a slight decline or no change in firing in response to stretching of a fatigued muscle.³³ It is unclear how fatigued a muscle must become for an EAMC to occur or whether the neuromuscular fatigue is occurring peripherally or centrally.²³ In other words, there is no true treatment or protocol to get consistent and reliable results that can be generalized to the entire population. Normal human muscle recruitment patterns indicate stimulation frequencies much lower than those used to induce fatigue in animal studies.³⁴ It is also unlikely that neuromuscular fatigue induced with electrical stimulation is the same as fatigue induced

with volitional muscle contractions given that large diameter motor neurons are stimulated first with electrical stimulation and last with volitional contractions.^{35, 36}

Laboratory induced muscle cramps are similar to a natural muscle cramp in the body, but being able to truly duplicate a natural muscle cramp is a challenge. Artificially induced cramping can cause some changes in the body system not guaranteeing a true result.

Exercise Induced Muscle Cramps

Controlling a cramp in a laboratory can be challenging.¹⁵ The method involves applying a single train of electrical impulses to a peripheral nerve, which will then cause muscle cramps.³⁹ The stimulation frequency is increased sequentially until a cramp develops.³⁹ The frequency of stimulation at which a cramp originates is termed threshold frequency.³⁹ Threshold frequency is thought to represent one's propensity to cramp and has been shown to be a reliable measure gauge within participants.^{15, 39} Any intervention that affects an individual's tendency to develop a cramp should manifest as a shift in the threshold frequency from a previously established baseline.³⁹

Percutaneous electrical stimulation to the tibial nerve is one of the preferred interventions to induce a muscle cramp. It is reliable and tolerated well by individuals,^{23,40-41} The procedure is also highly associated with the occurrence of EAMC.^{23,41} With this procedure the tibial nerve is stimulated with low frequency trains of electrical stimulation frequency at which the muscle cramps and this is termed "threshold frequency".²³ Due to the fact that lower cramp TF are associated with the occurrence of EAMC⁴⁰, TF may be used as a quantitative measurement of an individual's cramp susceptibility.²³

Summary

Throughout the various research studies it has been made clear that there is no hard evidence to determine the actual cause of muscle cramps. There is evidence to show that some of the theories require each other to induce a natural muscle cramp. When talking about the dehydration and electrolyte imbalance it has been stated that one does not usually happen without the other. It can be from one factor or multiple factors, a person can be predisposed to having them or they can be building up because they have major muscle fatigue. The goal should be to try and isolate different factors like humidity, sweat loss, dehydration, and or fatigue to try and discover if one of the factors is more likely to cause muscle cramps over the other factors. Much more research will be needed to discover why the muscle cramps are happening.

CHAPTER 3. METHODS

The purpose of the study was to determine if fatigue contributes to exercise associated muscle cramps in individuals who have a history of exercise associated muscle cramps. Cramp threshold frequency will be measured using the flexor hallucis longus muscle because of its ability to cramp by electrical stimulation. This study will examine if cramp threshold frequency is lower in a fatigued flexor hallucis longus muscle than in rested flexor hallucis longus muscle.

Experimental Design

Differences between cramp TF when flexor hallucis longus was rested versus fatigued were evaluated with a paired pretest-posttest design. The independent variable will be fatigue condition (prior to fatigue protocol, then after fatigue protocol); while the dependent variable will be threshold frequency.

Participants

Based on previous research, ten healthy 18-32 aged women with a history of muscle cramps were recruited to participate in the study (see appendix A).¹⁻² Subjects were excluded if: 1) a cramp could not be induced in their dominant flexor hallucis longus 2) they are unable to handle the discomfort of the cramp; 3) they have had a lower extremity injury or surgery within the six months before the beginning of the study; 4) they have any neurological (e.g. multiple sclerosis) and or cardiovascular (e.g. arrhythmias) issues; 5) are taking any medications that alter neuromuscular, metabolism, or thermoregulators (see appendix B). Subjects signed a written informed consent approved by the university's IRB committee and filled out a health screening form (see appendix C), which determined eligibility for the study.

Instrumentation

A GRASS S88 stimulator with SIU5 Stimulus Isolation Unit (Astro-Med, Inc., West Warwick, RI) with an 8mm Ag/AgCl-shielded active electrode (EL258S; Biopac Systems) and an 8-cm square dispersive electrode was used to deliver the train of electrical stimuli. Stimulus intensity was set at 80 V because this intensity has been shown to induce muscle cramps in healthy subjects.

An EMG will record muscle potential using the MP150 analog-digital data acquisition system with *Acqknowledge* software (version 3.7.3; Biopac Systems, Inc)

Procedures

Subjects were supine on the table. To prepare their dominant lower leg for testing, the co-investigator determined the exact location of the flexor hallucis longus and identified an area around the big toe where the electrodes were applied. In addition, the co-investigator removed hair around the knee if needed and lightly scratch the following areas using fine sandpaper: 1) the knee, 2) your big toe, and 3) the inside of the ankle. The co-investigator will apply alcohol to these areas and the electrodes will be applied. The subject's tibial pulse was found behind the inside of their ankle and was used to find the posterior tibial nerve. Electrical stimulation was used to find a strong contraction for the flexor halluces longus. A small round pad was placed to outside of the ankle while a separate round pad was applied to the inside portion of their ankle to stimulate the nerve. While trying to locate the nerve, the area was stimulated 2-4 times to find the exact location. The subject was informed what kind of sensation they will be feeling when the stimulation is administered. The sensation felt like tapping on the inside of their ankle and a pins and needles feeling. If the subject was unable to cramp after the bout of

stimulation, they rested for one minute. This process was repeated until a cramp occurred. After the cramp occurred, the subject rested for 30 minutes prior to beginning the fatigue protocol.

For the fatiguing protocol, the subject was in the supine position. The subject then performed reps of toe curls against a resistance band. The subject completed sets of 10 curls with a one minute break in between sets; reps continued until muscle failure.⁴³ To ensure that the subject did not use other muscles to assist with the toe curls, the legs were secured to the table with a nylon strap. Immediately after fatigue protocol is completed the participant began the second bout of cramping. Participants received a stipend of \$30 for participating in the study. If the subject was unable to complete the study or a cramp could not be induced they received \$10.

Statistical Analysis

Differences between cramp threshold frequency when fatigued and not fatigued were analyzed with a paired T-test. Independent variable being the fatigued condition and the dependent variable would be cramp threshold frequency.

**CHAPTER 4. MANUSCRIPT: CRAMP THRESHOLD FREQUENCY IN A
FATIGUED FLEXOR HALLICUS LONGUS WHEN COMPARED TO A
RESTED FLEXOR HALLICUS LONGUS**

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Introduction

Muscle cramps are a painful, spasmodic contraction of skeletal muscle that occur during or after physical exercise.¹ Muscle cramps are a common injury that affect many physically active individuals in a variety of sports and activities.²⁻⁴ Cooper et al² found that 73.4% of football players experienced heat cramps whereas another study found that a total of 62-78% triathletes have complained of exercise associated muscle cramps (EAMC) while racing and training.⁴ Exercises associated muscle cramps are not specific to just athletes. A separate study discovered that 95% of physical education students experienced spontaneous cramps in their lifetimes with 26 % reports associated cramps after exercise. Although there is a wide variety of people experiencing EAMC, the cause of them is unclear.

A variety of popular theories exist as to the cause of exercise associated muscle cramps (EAMCs) including environmental factors, dehydration, electrolyte imbalance, and fatigue^{4,8,9} Although, there are multiple theories regarding the cause of cramping, the true causes are unknown.

Researchers have theorized neural control is responsible for EAMC.^{5,6} The neuromuscular theory of EAMC proposes that fatigue creates an imbalance between excitatory and inhibitory signals which alter excitability alpha motor neuron. After a muscle is fatigued, the alpha motor neuron causes the muscle cramp because they are consistently firing. This does not allow the muscle to relax in its necessary way. The alpha motor neuron over firing will cause the muscle to become over stimulated and cause an EAMCs. Because muscle fatigue occurs over time, and because EAMCs often occur at the end of longer and intense races, it would seem that fatigue causes EAMCs.⁷

One study conducted by Stone et al.⁴² evaluated the effect of local muscle fatigue on the threshold frequency of an electrically induced muscle cramp. Stone et al.⁴² conducted the study with two groups, control and fatigue groups. An increase in threshold frequency seems to demonstrate a decrease in one's propensity to cramp following the fatigue.⁴² Stone et al.⁴² found no difference between baseline and fatigued muscle. Because this contradicts the theory, the purpose of this study is to determine if fatigue indeed cause EAMCs.

Methods

Participants

Ten healthy females, with a history of EAMCs (age= 20 \pm 1.9 years, height=65.3 \pm 2.9 inches, and mass=145 \pm 17.05 pounds) were included in the study. Subjects were excluded if: 1) a cramp could not be induced in their dominate flexor hallucis longus 2) they were unable to handle the discomfort of the cramp; 3) they had a lower extremity injury or surgery within the six months before the beginning of the study; 4) they had any neurological (e.g. multiple sclerosis) and or cardiovascular (e.g. arrythmias) issues; 5) took any medications that alter neuromuscular, metabolism, or thermoregulators (see appendix B). Subjects then completed an IRB approved health screening form (see appendix C), which determined if they were eligible for the study.

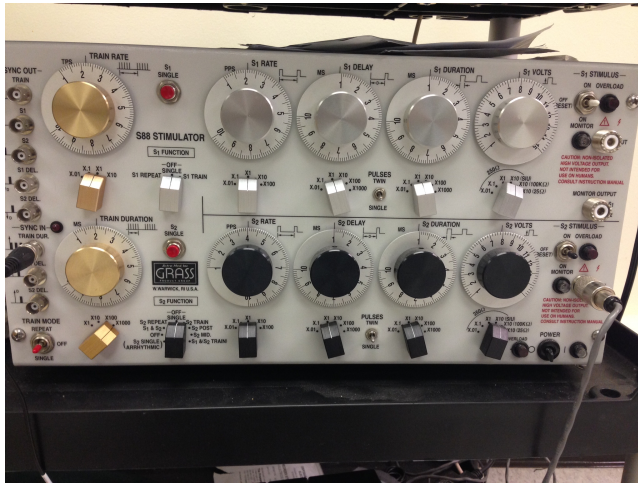
Instruments

A GRASS S88 stimulator (see figure 1) with SIU5 Stimulus Isolation Unit (Astro-Med, Inc., West Warwick, RI) with an 8mm Ag/AgCl-shielded active electrode (EL258S; Biopac Systems) and an 8-cm square dispersive electrode was used to deliver the train of

electrical stimuli to induce muscle cramping. Stimulus intensity was set at 80 V because this intensity has been shown to induce muscle cramps in healthy subjects.⁴²

An EMG will record muscle potential using the MP150 analog-digital data acquisition system with *Acqknowledge* software (version 3.7.3; Biopac Systems, Inc)

Figure 1. GRASS stimulator.



Procedures

After subjects signed a written informed consent and completed a health history form, they were asked to lay supine on a treatment table. The investigator removed the hair around the knee and lightly scratched the following areas using fine sandpaper: 1) the knee, 2) the big toe, and 3) the inside of the ankle and cleaned the area with alcohol. Extending the great toe identified the exact location of the flexor hallucis longus and the Ag/AgCl-shielded electrodes were applied to cleaned areas (See figure 2, 3 and 4). The subject's posterior tibial pulse was also located and marked with a black permanent marker, so the investigator had an idea where to apply the stimulus. Electrical stimulation provided by the GRASS S88 stimulator was used to find a strong contraction for the flexor hallucis longus. A small round electrodes was placed to outside of the ankle while

a separate round electrodes was applied to the inside portion of the subject's ankle to stimulate the nerve. The two electrodes created a closed circuit for the electrical stimulation.

Figure 2. Electrode placement.

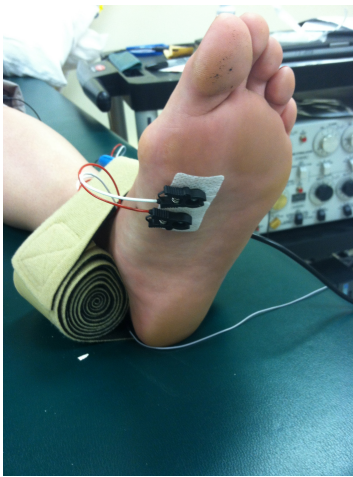


Figure 3. Electrode placement.

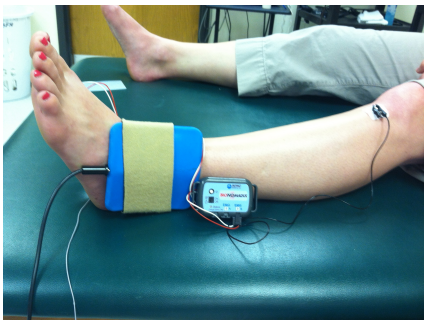


Figure 4. Electrode placement.



The area was stimulated 2-4 times to find the exact location of the nerve. Once the nerve was located, the electrodes on both sides of the ankles were re-applied with tape to establish the correct location and secured with elastic wrap. The subject was informed that they would feel the stimulation just below the medial malleolus. If the subject was unable to cramp after the bout of stimulation, they rested for one minute and the process was repeated until a cramp occurred. Once an initial cramp occurred and baseline threshold frequency (TF) was recorded, the subject rested for 30 minutes before a fatigue protocol began. For the fatiguing protocol the subject was placed in the supine position and performed reps of toe curls (sets of 10 curls with a one minute break) against a resistance band until muscle failure.⁴³ To ensure that the subject did not use other muscles to assist with the toe curls, the leg was secured to the table with a nylon strap. If the subject lifted the leg off the table more than three times in a row to curl the toe or did not bend the toe completely more than three times in a row they were considered fatigued.

Immediately after fatigue protocol was completed the participant began the second bout of cramping to obtain the cramp TF.

Statistical Analysis

The independent variable for this study was the fatigued condition and the dependent variable was cramp threshold frequency. Differences between cramp TF when flexor hallicus longus was rested verses fatigued were analyzed with a paired T-test.

Results

Figure 5 displays the TF for each of the participants. Of the 10 participants, six had a lower posttest TF than pretest, while three had higher TF than their pretest there was also one subject who had the same pretest and posttest which was an outlier for the data (figure 5). There is not a statistically significant difference between baseline and fatigued muscle's cramp frequency threshold ($t(9) = 1.69, p > .05$). Although not statistically significant, results revealed a slight difference between the mean cramp TF (see figure 6) in a fatigued flexor hallicus longus (25.80 ± 7.33) when compared to a rested flexor hallicus longus (28.20 ± 7.91). It can see the mean fatigued flexor hallus longus threshold frequency scores are less than the mean baseline flexor hallus longus threshold frequency scores.

Figure 5. Threshold frequencies charted for each individual participant. Comparisons between pretest and posttest are displayed.

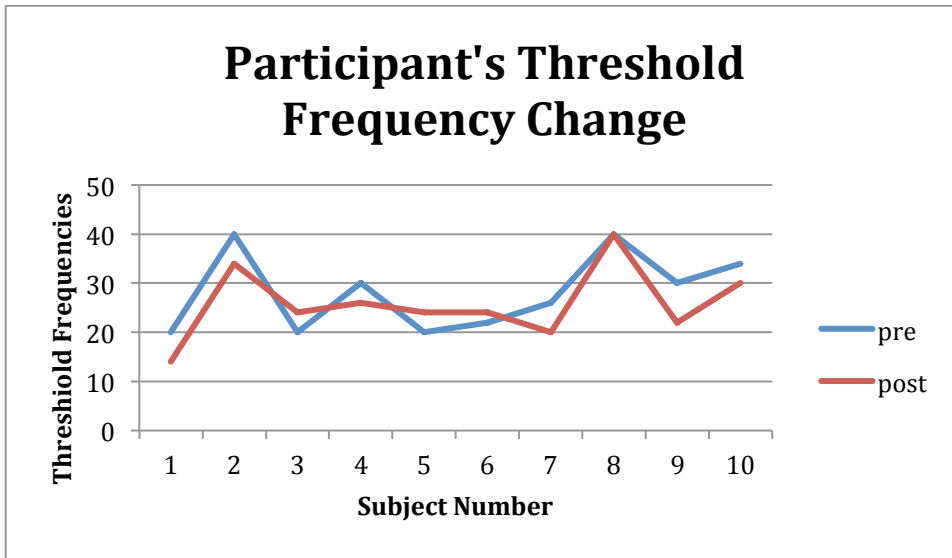
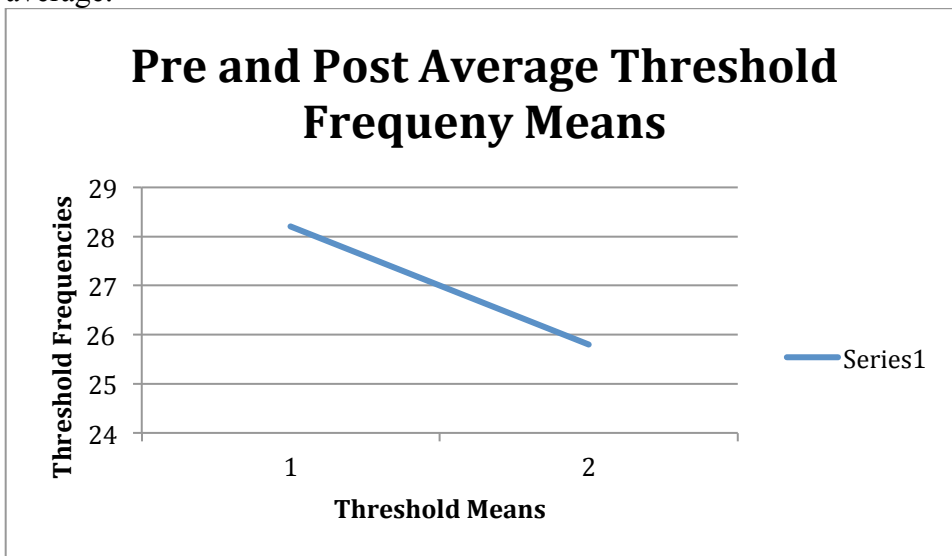


Figure 6. The figure below displays the means of all of the pretest and posttest threshold frequencies. There is a noticeable change between the pretest average and posttest average.



CHAPTER 5. DISCUSSION

The purpose of the study was to determine if fatigue contributes to EAMCs in individuals who have history of EAMC. The cramp TF was not statistically significantly lower in a fatigued flexor hallicus longus compared to the baseline flexor hallicus longus among individuals who have a history of EAMCs ($t(9)=1.69$, $p>.050$). However, we did notice a difference between the mean cramp threshold frequencies of a fatigued flexor hallicus longus and a rested flexor hallicus longus, $25.80\text{Hz} \pm 7.33$ and $28.20\text{Hz} \pm 7.91$ respectively (See Figure 6).

Current fatigue theory states that EAMCs develop from within the spinal cord itself, not from external contributors.⁵ After the flexor hallicus longus muscle was flexed a repeated number of times until the toe could no longer complete full flexion; the alpha motor neurons are consistently firing not allowing the muscle to relax in its necessary way. This alpha motor neuron over firing will cause the flexor hallicus longus to become over stimulated and then will cause a EAMCs. The over firing was accomplished with the toe curls the participants were required to perform until failure.

The recent study we completed conflicts with the existing neuromuscular fatigue theory as the reason behind an EAMCs. The current study's results showed that fatigue is not a significant factor in a person experiencing EAMCs. Although not statistically significant there was a mean difference decrease in cramp threshold frequency in the fatigued flexor hallicus longus muscle compared to rested.

Findings from a similar study⁴² concur with the current study findings. The purpose of Stone et al⁴² study was to determine the effect of local muscle fatigue on the threshold frequency of an electrically induced muscle cramp. To determine baseline

threshold frequency, a cramp was electrically induced in the flexor hallucis brevis of 16 apparently healthy participants (7 males, 9 females; age 25.1 ± 4.8 years). The testing order of control and fatigue conditions was counterbalanced. In the control condition, participants rested in a supine position for 30 min followed by another cramp induction to determine post-threshold frequency. In the fatigue condition, participants performed five bouts of great toe curls at 60% one-repetition maximum to failure with 1 min rest between bouts followed immediately by a post-threshold frequency measurement.⁴² Mean post-fatigue threshold frequency (32.9 ± 11.7 Hz) was higher ($P < 0.001$) than pre-fatigue threshold frequency (20.0 ± 7.7 Hz) among the sample of participants.⁴² Our results held true to what Stone et al.⁴² found during their research, with the results of TF contradiction current neuromuscular theory.

There are some differences in the methods among fatigue induced EAMCs studies. Stone et al.'s study⁴² used slightly different inclusion and exclusion criteria. The current study focused on female subjects and who had a younger mean age. The mean age of the current study is 20 ± 1.9 years while the mean age of Stone et al. study was 25.1 ± 4.8 years. It is unclear in Stone et al.'s study whether or not the participants had a history of EAMCs whereas in the current study they did. This is important because individuals who have experienced muscle cramps before generally have a lower TF than those who have never experienced a cramp.²³ With a lower TF a person will cramp much sooner than a person who has a higher TF.

Clinical Implications

Clinical implications from the study show that fatigue may not be the reason behind a person's EAMCs. Because of this medical professionals should continue to treat

EAMCs in the ways that have been working for them. The goal is to have athletes and physically active people return as quickly as possible from EAMCs.

Limitations

As with all good studies, there are some limitations. One limitation is the overall sample size. A total of ten participants were selected for this study because similar studies used a similar sample size.⁴² However, this sample size may be too small to detect the subtle changes between rested and fatigued conditions.

A second limitation of the study is the sample selection. We delimited to female subjects, which makes it difficult to generalize to different samples. While only using female subjects was a delimitation it also made this study unique. There are few studies that focus solely on female subjects, so the study provides new insights on how females react to EAMCs.

Future Research

Future studies should focus on a larger sample size and consider expanding the demographics of the sample. Future research should also investigate other theories for EAMCs such as environmental, electrolyte imbalance, and dehydration. As well as examine if a combination of the different theories is the reason behind EAMCs.

Conclusion

Although EAMCs are a common injury, fatigue does not appear to be a main contributor to muscle cramps. However, we did notice a decrease in a person's cramp TF will lower after completing a fatiguing protocol. A larger sample would be required to determine if fatigue has a major affect on EAMCs. Medical professionals should continue to treat EAMCs in any way that has been successful for them.

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APPENDIX A. RECRUITMENT SCRIPT

Recruitment Script/Email

My name is Alexandra Drayton and I am a graduate student in the HNES department at North Dakota State University. Dr. Pamela Hansen and I are performing a study titled “Cramp Threshold Frequency in a Fatigued Flexor Hallicus Longus (Big Toe) Compared to a Rested Flexor Hallicus Longus (Big Toe)”. We want to determine if the cause of a muscle cramp is due to fatigue. Your participation time includes approximately 1.5-2 hours.

The requirements for you to participate include: you are a healthy male or female between the ages of 18-32; you have no history of cardiovascular (arrhythmia) or neurological (multiple sclerosis) diseases; you have a history of muscle cramps in the last six months, any muscle cramp during or after exercise; you have no injuries or surgery to your lower dominant lower leg within the last six months; you are not taking any medications that alter neuromuscular, metabolism, or thermoregulators.

You will come to Room 14 in the Bentson Bunker Fieldhouse for one day of testing. You will need to wear shorts and tennis shoes to the testing. You will need to come hydrated and have not participated in exercise at least 24 hours prior to the testing. You will fill out a health questionnaire and sign informed consent prior to starting. After you have completed the paperwork, the cramping protocol and fatiguing protocol will begin.

The risks to you are minor. There is potential to experience discomfort from the cramping protocol and the lower dominant leg may feel tired or weak after the fatiguing protocol.

You will be reimbursed \$30 for your time which will be apporximately 1.5-2 hours. You will be compensated \$10 if you are unable to cramp or is you are unable to handle the discomfort of the cramp. Participation in this study is completely voluntary and not mandatory in any way, and does not have any effect on your academic standing at NDSU. If you are interested or have any questions, please contact Pamela Hansen at Pamela.J.Hansen@ndsu.edu (701) 231-8093 or Alexandra Drayton at alexandra.drayton@ndsu.edu (612) 508-1331. Thank you.

APPENDIX B. INFORMED CONSENT

NDSU North Dakota State University
Dept. of Health, Nutrition, and Exercise Sciences
PO Box 6050 Dept. 260
Fargo, ND 58108-6050
701-231-8093

Title of Research Study: Cramp Threshold Frequency in a Fatigued Flexor Hallucis Longus (Big Toe) Muscle Compared to a Rested Flexor Hallucis Longus Muscle

This study is being conducted by: Dr. Pamela Hansen EdD; Alexandra Drayton, ATC

Why am I being asked to take part in this research study? You are being asked to participate in this study because you are a healthy male or female between the ages of 18-32 with a history of cramping. You will not be allowed to participate in the study if: 1) if you have had a injury or surgery to your lower leg within the past six months; 2) if you have any nerve or heart/lung issues; 3) if you are taking any medications for vascular or neurological disorders.

What is the reason for doing the study? The purpose of the study is to determine if fatigue contributes to muscle cramps. Your big toe muscle will be used because of its size and how susceptible it is to muscle cramping.

What will I be asked to do?

You will come to the BBF (Athletic Training Research Lab) for one day of testing. When you arrive, you will be asked to complete a health questionnaire and sign the informed consent.

You will lie on your back on the table. Your knee, big toe and the inside of your ankle will be shaved if needed, lightly rubbed with fine sand paper, and then cleaned with alcohol. The pulse down by your foot will be located and marked. Electrical stimulation will be used to find a strong contraction in your big toe. A small round pad will be placed to outside of your ankle while a separate round pad will be applied to the inside portion of your ankle to stimulate the nerve. Once the nerve is located, the pads on both sides of the ankles will be re-applied with tape to secure the correct location and secured with elastic wrap.

Before the cramping protocol begins you will be advised of the type of sensation you will feel. The sensation of the cramping protocol will be a taping on the middle of your calf

and will have a pins and needles feeling. If you do not cramp, you will have a minute rest in between the stimulation bouts the process continues until a cramp has occurred.

After the 30-minute rest period you will begin the fatiguing process. You will perform reps of toe curls against a resistance band while your legs being secured to the table with a nylon strap. You will be asked to complete sets of 10 curls with a one minute break in between sets. You will continue doing reps until muscle failure is determined. Immediately after the fatigue protocol is completed the participant will begin the second bout of cramping.

Where is the study going to take place, and how long will it take? BBF Room 14 (Athletic Training Research Lab). Testing will take approximately 1.5-2 hours of your time.

What are the risks and discomforts? You may have some discomfort from the cramping protocol, but this will be well monitored. The dominant lower leg may become tired and feel weak from the fatiguing process. It is not possible to identify all potential risks in research procedures, but the researcher(s) have taken reasonable safeguards to minimize any known risks to the participant.

What are the benefits to me? You are not likely to gain any benefit from being in this research study. However, if you are a student, you may gain some benefit by seeing how experimental research is performed.

What are the benefits to other people? Muscle cramps are common in physically active individuals. Although there is limited research, fatigue is one idea being investigated. This research project can potentially help physically active individuals identify the cause of cramps.

Do I have to take part in the study? Your participation in this research is your choice. If you decide to participate in the study, you may change your mind and stop participating at any time without penalty or loss of benefits to which you are already entitled.

What will it cost me to participate? There is no monetary cost to you.

What are the alternatives to being in this research study? You may choose not to participate in the study.

Who will see the information that I give? All research records that identify you will be kept confidential. If a manuscript is written, results from data collection will be analyzed as a group therefore not identifying any one individual in the study. Every effort to prevent anyone who is not on the research team from knowing your information will be made. For example, your name will be kept separate from your search records and these two things will be stored in different places under lock and key.

Can my taking part in the study end early? If you fail to show up to your session you will be removed from the study and may not receive your monetary compensation. If you are unable to experience a muscle cramp, you will be paid \$10 for your time and removed from the study.

Will I receive any compensation for taking part in this study? You will come in for one day of testing which will be approximately 1.5-2 hours. If you are able to complete the day of testing you will receive \$30 for your time. If you are unable to cramp they will be compensated \$10 for your time.

What happens if I am injured because of this research? (Include if applicable)
If you receive an injury in the course of taking part in the research, you should contact the chief investigator, Dr. Pamela Hansen at (701) 231-8093 or the co-investigator, Alexandra Drayton at (612) 508-1331. Treatment for the injury will be available including first aid, emergency treatment and follow-up care as needed. Payment for this treatment must be provided by you and your third party payer (such as health insurance or Medicare). This does not mean that you are releasing or waiving any legal right you might have against the researcher or NDSU as a result of your participation in this research.

What if I have questions?

Before you decide whether to accept this invitation to take part in the research study, please ask any questions that might come to mind now. Later, if you have any questions about the study, you can contact the chief investigator, Dr. Pamela Hansen at (701) 231-8093 or Pamela.J.Hansen@ndsu.edu and co-investigator, Alexandra Drayton at (612) 508-1331 or alexandra.drayton@ndsu.edu.

What are my rights as a research participant?

You have rights as a participant in research. If you have questions about your rights, or complaints about this research [may add, “or to report a research-related injury” if applicable], you may talk to the researcher or contact the NDSU Human Research Protection Program by:

- Telephone: 701.231.8908 or toll-free 1-855-800-6717
- Email: ndsu.irb@ndsu.edu
- Mail: NDSU HRPP Office, NDSU Dept. 4000, PO Box 6050, Fargo, ND 58108-6050.

The role of the Human Research Protection Program is to see that your rights are protected in this research; more information about your rights can be found at: www.ndsu.edu/irb.

Documentation of Informed Consent:

You are freely making a decision whether to be in this research study. Signing this form means that

1. you have read and understood this consent form
2. you have had your questions answered, and
3. you have decided to be in the study.

You will be given a copy of this consent form to keep.

Your signature

Date

Your printed name

Signature of researcher explaining study

Date

Printed name of researcher explaining study

APPENDIX C. HEALTH SCREENING FORM

Cramp Threshold Frequency in a Fatigued Flexor Hallicus Longus Compared to a Rested Flexor Hallicus Longus

Health Screen Form

Identification Code: _____

Age: _____

Gender:

Male

Female

Height: _____

Weight: _____

Dominate Leg: _____

1. Have you had a cramp in the last 6 months?

Yes

No

2. Any injury or surgery to your lower leg in the past 6 months?

Yes

No

3. Do you have any cardiovascular or neurological disorders?

Yes

No

4. Are you taking any medications that alter neuromuscular, thermoregulators, or metabolism?

Yes

No

If you have answered yes to any of the questions you will be eliminated from the study.